Smart Pet Monitoring System

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Abstract

Smart Pet Monitoring System is a real-time, AI-powered solution designed to assist pet owners with behavior-based training and remote monitoring. The system consists of a Raspberry Pi-based smart bowl, a Flutter mobile app, and a FastAPI server.

By using object detection and keypoint-based posture analysis, the system detects pooping behavior of pets. If the behavior is detected within the predefined training pad area, the system automatically dispenses a reward. Users can also manually control feeding, monitor live video, and capture snapshots via the mobile application.

This project enhances pet toilet training efficiency and provides a practical, low-cost solution for remote pet care.

AI Models Overview

The system utilizes three lightweight YOLOv11 Nano-based AI models, each specialized for a different task:

🔍 **Model 1: General Object Detection**
Detects cats and dogs in the frame and checks if the pet is stationary. Acts as the trigger for other models.

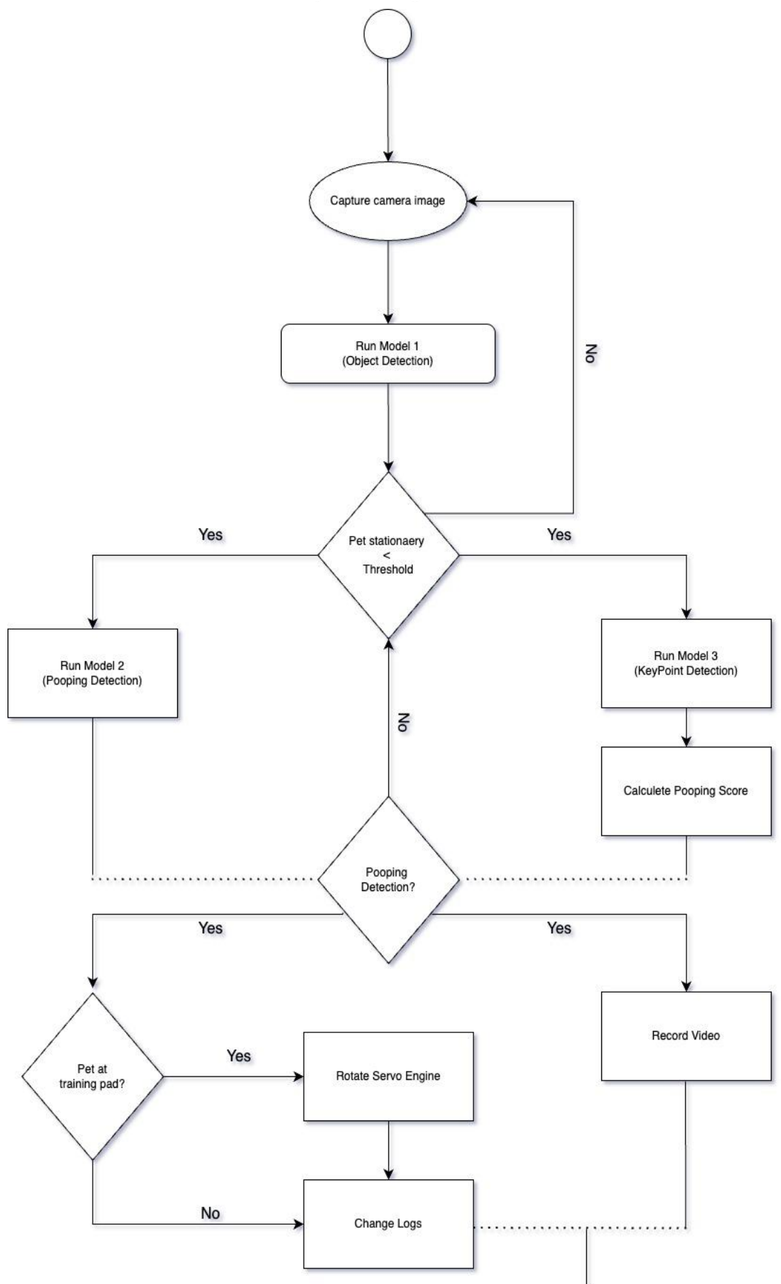
F1 Score ≈ 0.73 (Precision: 0.768, Recall: 0.695)

💩 **Model 2: Pooping Detection**
Classifies pet behavior into four categories:
Normal, **Pooping**, **Scratching**, **Sitting**

F1 Score ≈ 0.955 (Precision: 0.951, Recall: 0.958)
Trained on 2,331 images with data augmentation

🦴 **Model 3: Keypoint Detection**
Detects 24 anatomical landmarks of the pet (e.g., paws, knees, tail, nose).
Used to evaluate pet posture and calculate a pooping score.

F1 Score ≈ 0.934 (Precision: 0.927, Recall: 0.941)
Trained on Ultralytics Dog Pose dataset

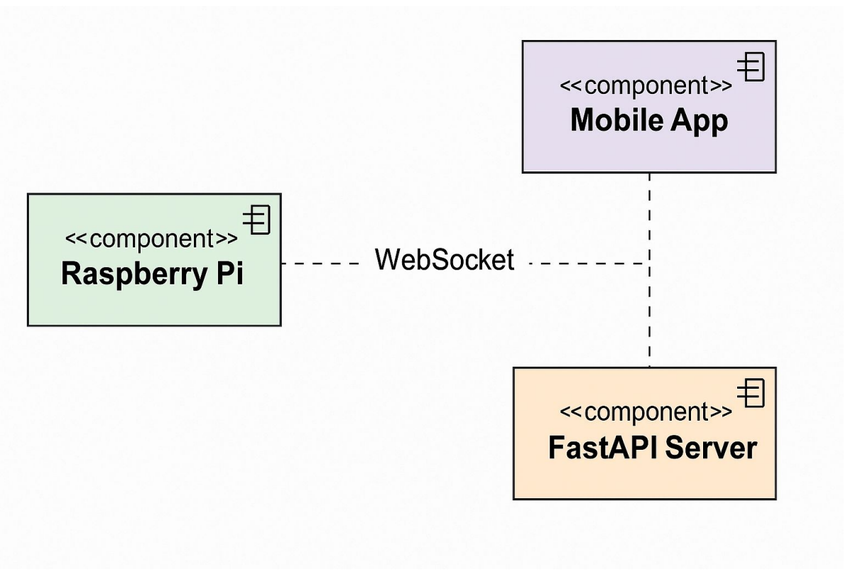


Activity Diagram

System Architecture

The Smart Pet Monitoring System is built with a modular architecture consisting of three main components:

- **Flutter Mobile Application**: Allows users to watch the live stream, feed pets, and activate detection.
- **FastAPI Server**: Handles user/device registration and communication via HTTP and WebSocket protocols.
- **Raspberry Pi Smart Bowl**: Equipped with a camera and servo motor, it runs AI models for behavior detection and dispenses food based on system decisions.

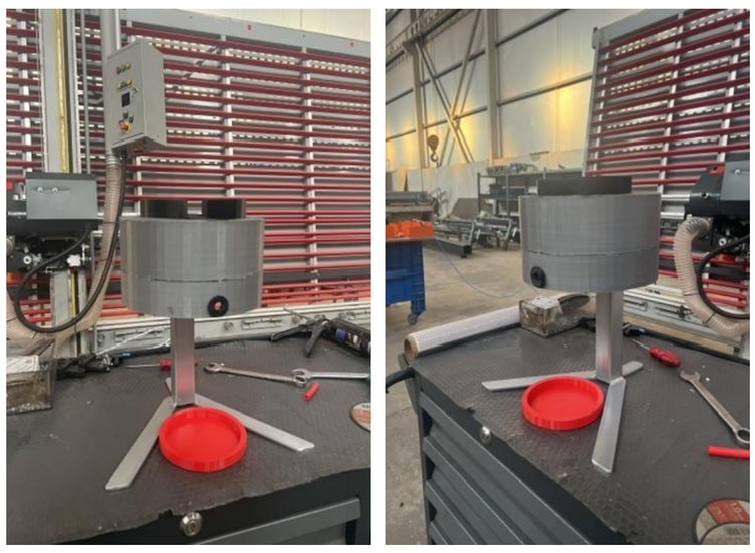


System Components

Smart Bowl

The smart bowl is powered by a **Raspberry Pi 5** equipped with:

- 📷 **Camera Module** for real-time streaming and behavior detection
- 🔄 **Servo Motor** for reward food dispensing
- ⚙️ **On-device AI** (YOLOv11 models running in real-time)
- 🔌 Fully autonomous and synchronized via **WebSocket** communication



It processes video locally, detects pooping behavior using onboard AI, and dispenses reward food if the behavior occurs on the training pad.

Decision Mechanism (Trigger → Analysis → Reward)

1. **Trigger Stage**
   Model 1 continuously monitors the environment.
   If the pet (dog/cat) is detected and remains stationary for several frames,
   👉 it triggers Model 2 and Model 3.

2. **Parallel Analysis Stage**
   - **Model 2 (Object Detection):** Classifies the pet's posture (Pooping / Normal / Sitting / Scratching).
   -**Model 3 (Keypoint Detection):** Detects 24 body landmarks and calculates a custom pooping score.

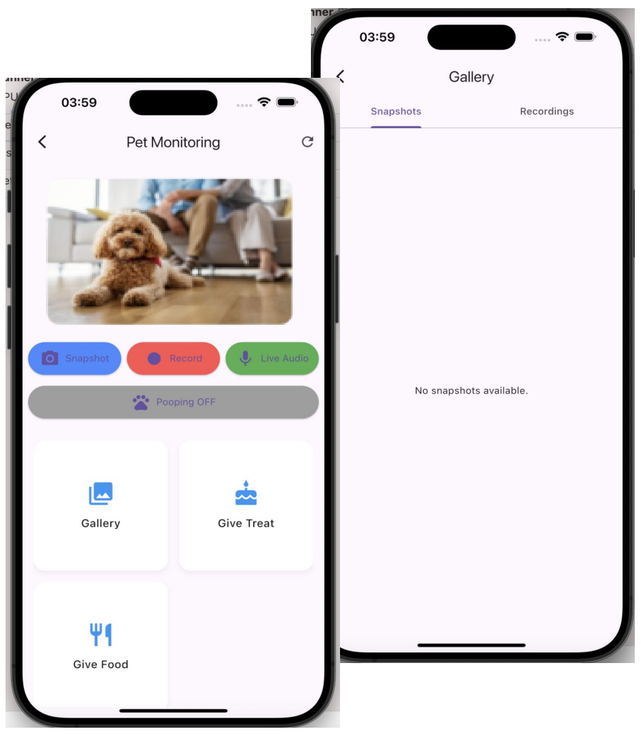
3. **Score Evaluation Stage**
   If Model 2 detects **"Pooping"** with confidence > 50% and the following condition is met:

   Pooping Score = (Keypoint Position Score × Keypoint Accuracy) + Model 2 Score
   → if score > **100 threshold** ➡️ considered valid.

4. **Reward Stage**
   If the pet is on the user-defined **training pad**,
   ➡ The **servo motor activates** to release reward food.
   A video recording is also started automatically.

Mobile Application

The mobile application—built with **Flutter**—serves as the primary user interface for interacting with the Smart Pet Monitoring System. It offers the following key functionalities:



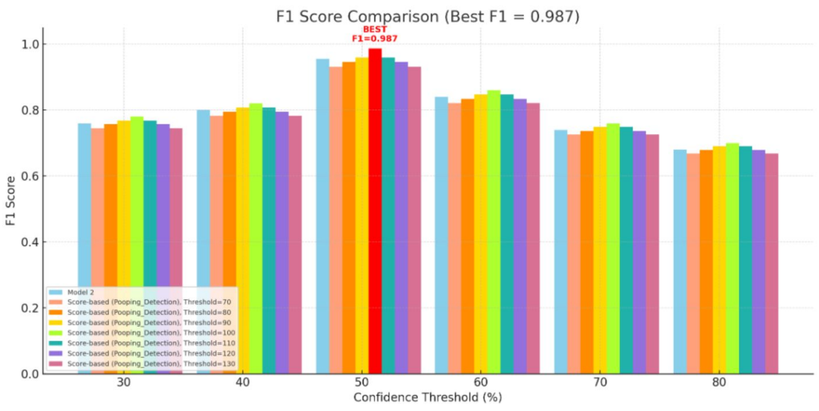
- 📡 **Live Streaming**: Real-time view of the pet's environment via Raspberry Pi camera.
- 📸 **Snapshot & Video Recording**: Users can capture and store media on demand.
- 🥣 **Manual Feeding**: Dispense regular or reward food through dedicated buttons.
- 💩 **Pooping Detection Activation**: Starts real-time behavior detection and reward mechanism.
- 📂 **Media Gallery**: Access to saved photos and videos.
- 📍 **Manual Pad Marking**: If the system fails to auto-detect the training pad, users can manually mark coordinates through the interface.

Results

The system was evaluated under controlled test scenarios using video and image datasets.

Key performance outcomes include:

- ✅ **High Accuracy**: Achieved an overall **F1 Score of 0.987** using the hybrid decision mechanism.
- ⏱️ **Fast Response Time**: Average **servo activation delay** was measured at **1.1 seconds**, including model inference.
- ❌ **Reduced False Positives**: Compared to standalone detection, false positives were reduced by **46%** using the score-based approach.



📌 **Figure**:
Bar chart showing F1 Score comparison between Model 2 alone and the hybrid score-based method.

Future Work

- Add support for **cat-specific models** to expand to multi-pet environments.
- 📱 Implement **real-time mobile notifications** for pooping events.
- Integrate **infrared/night vision support** for low-light detection.
- Visualize keypoints and posture analysis in the mobile app for better user insight.

Referances

[1] Ultralytics. *YOLOv5 and YOLOv11 models*.

[2] Roboflow. *Pooping Detection Dataset*.

[3] Ultralytics. *Dog Pose Keypoint Dataset*.

[4] Raspberry Pi Foundation. *Raspberry Pi 5 Technical Specs*.

[5] OpenCV Library. Bradski, G., 2000.

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